DONOGHUE

Foundation Caissons for the Grower Building

Civil Engineering

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FOUNDATION CAISSONS

FOR THE

GROWER BUILDING

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

GEORGE TERRY DONOGHUE

ENTITLED FOUNDATION CAISSONS FOR THE

GROWER BUILDING

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering.

Ira O. Baker.

HEAD OF DEPARTMENT OF Civil Engineering.

FOUNDATION CAISSONS FOR THE GROWER BUILDING OF CHICAGO.

INTRODUCTION.

The securing of proper foundations for tall buildings in the business district of Chicago has long been a serious problem. In Chicago the strata are as follows: from 0 to -20 ft. a loosley compacted mixture of sand and clay; from -20 to -75 ft. practically a continuous layer of stiff clay with an occasional streak of sand; from -75 to -95 ft. hard-pan with frequent sand streaks; and from -95 to -106 ft. bed rock.

Until the past few years two methods of sinking foundations have been in vogue. One of these was to drive piles at close intervals all over the foundation area, and cut them off below the low-water line. The other method, known as the spread foundation, consisted of a column supported on a grillage of concrete and steel beams spread out over an area many times greater than that of the column. Neither of these two methods was uniformly successful for heavy buildings. A third method has been introduced comparatively recently which seems to have solved the problem. In this method a circular hole 4 ft. to 12 ft. in diameter is excavated to hard-pan or bed rock; then the hole is filled with concrete, and the column is placed directly upon it. This is called the caisson method. This paper proposes to describe a caisson foundation in which the caissons were sunk in some cases to hard-pan and in others to bed rock.

The caissons were built for the foundation of the Grower Building, located at the south-east corner of Madison Street and the Chicago River, Chicago. The work was carried on by the contract-

ing firm of Roemheld and Gallery. A large city water tunnel ran under the site of the building; and on account of this, the direction of the work was under the general supervision of the City Engineer, although the building was not to be used for public purposes.

Fig. 1, page 3, shows the positions of the caissons, which varied in diameter from 4 ft. 6 inches to 6 ft. 9 inches, depending upon the location, depth, and load to be carried.

SURVEYING OPERATIONS.

The work of locating the centers of the caissons was carried on with no little difficulty. The principal trouble was to secure permanent and intervisible instrument points. It was impracticable to establish points along the street in front of the property from which to shoot in the center lines of the caissons for three reasons. First, Madison Street at this point is on a steep approach to the bridge, and is 12 to 15 ft. above the ground line, thereby making accurate mesurements difficult. Second, the caissons were not arranged in regular rows. Third, a high bill-board fence was located along the building line in front of the site. See Fig. 2, page 5. It was useless to try to maintain permanent points on the site proper because they would be knocked out of line by dirt wagons, or be covered with debris.

In view of these facts it was necessary to establish permanent instrument points off the premises. Accordingly a base line was run along Market Street, and another along Madison Street all other points and lines were tied into these lines. From the base line A-B, Fig. 2, the line B-C was run, and then the line C-D

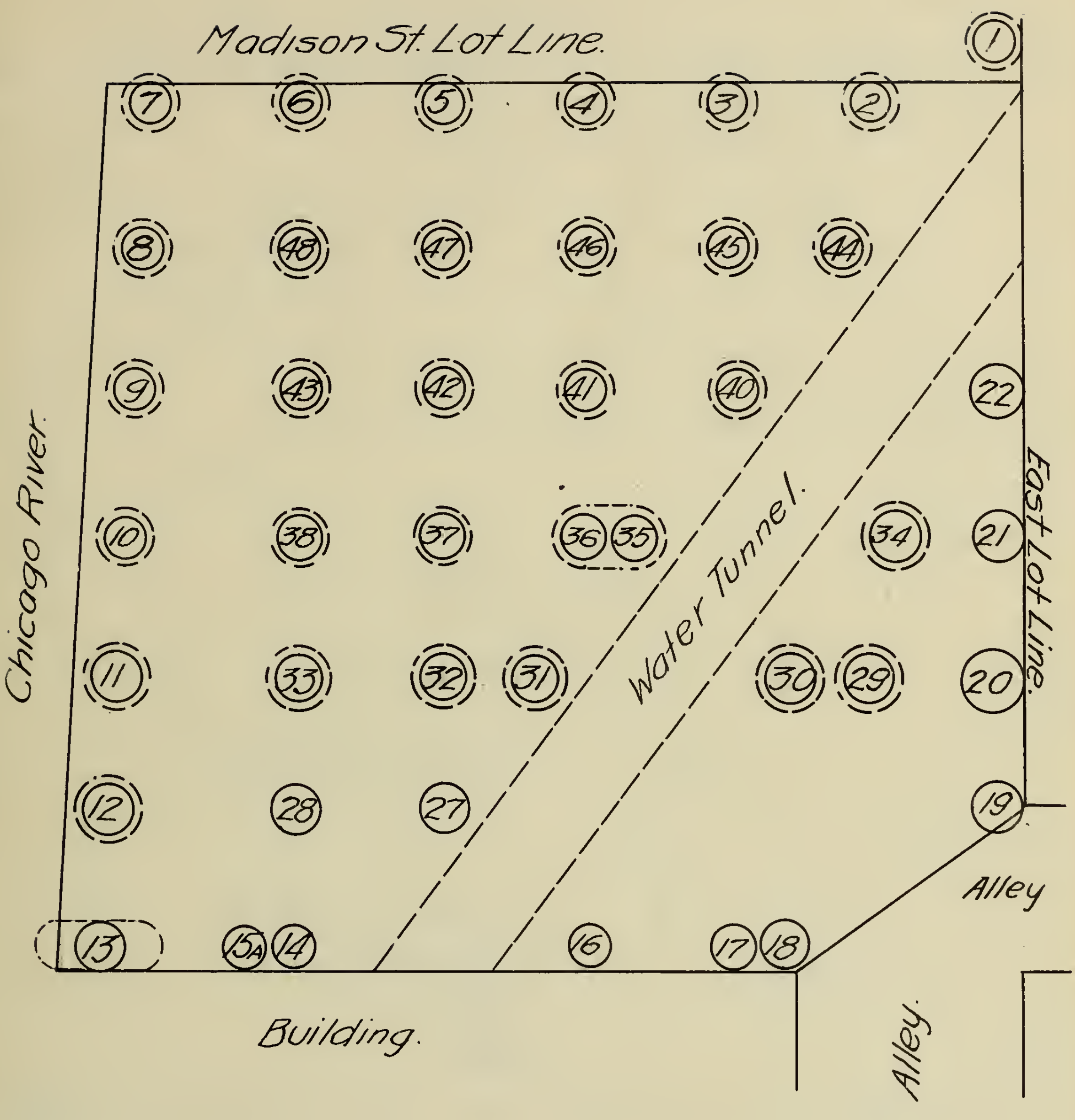

Fig. 1

THE LOCATION OF THE CAISSONS.

was established. Next points 1,2,3,4,5,6 were located on the line C-D. With these points located, lines 1-1,2-2,3-3, etc.,were run. Points 1 ,2 ,3 , now became permanent instrument stations,and from them the lines 1-1',2-2',3-3', were produced to the adjoining building,and were marked on the wall. With those lines and points located,the work of fixing the center of the caissons should have been an easy matter. However,the ground space was so small that every time a line was to be run in,a pile of lumber or something of that sort had to be moved. The surveying operations were therefore decidedly expensive.

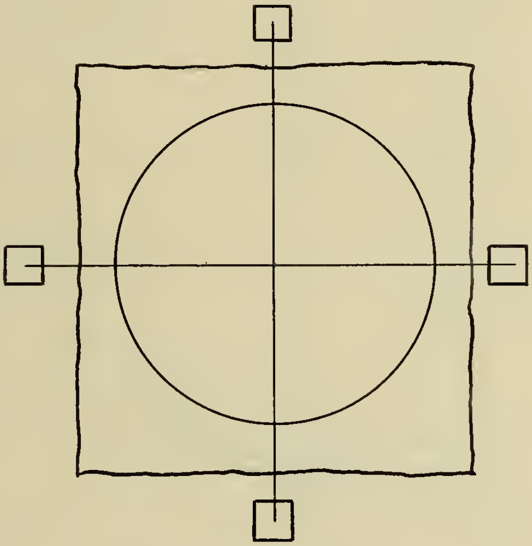

Fig.3.

METHOD OF LOCATING THE CENTER OF A CAISSON.

DESCRIPTION OF A CAISSON.

A caisson is a deep cylinder built in place varying usually from 75 to 105 ft. in depth,and from 4 to 12 ft. in diameter, made of wooden staves,called lagging,and iron rings upon the inside to preserve its form. The lagging consists of two-inch matched hard-pine plank in six-foot sections. Each section is braced

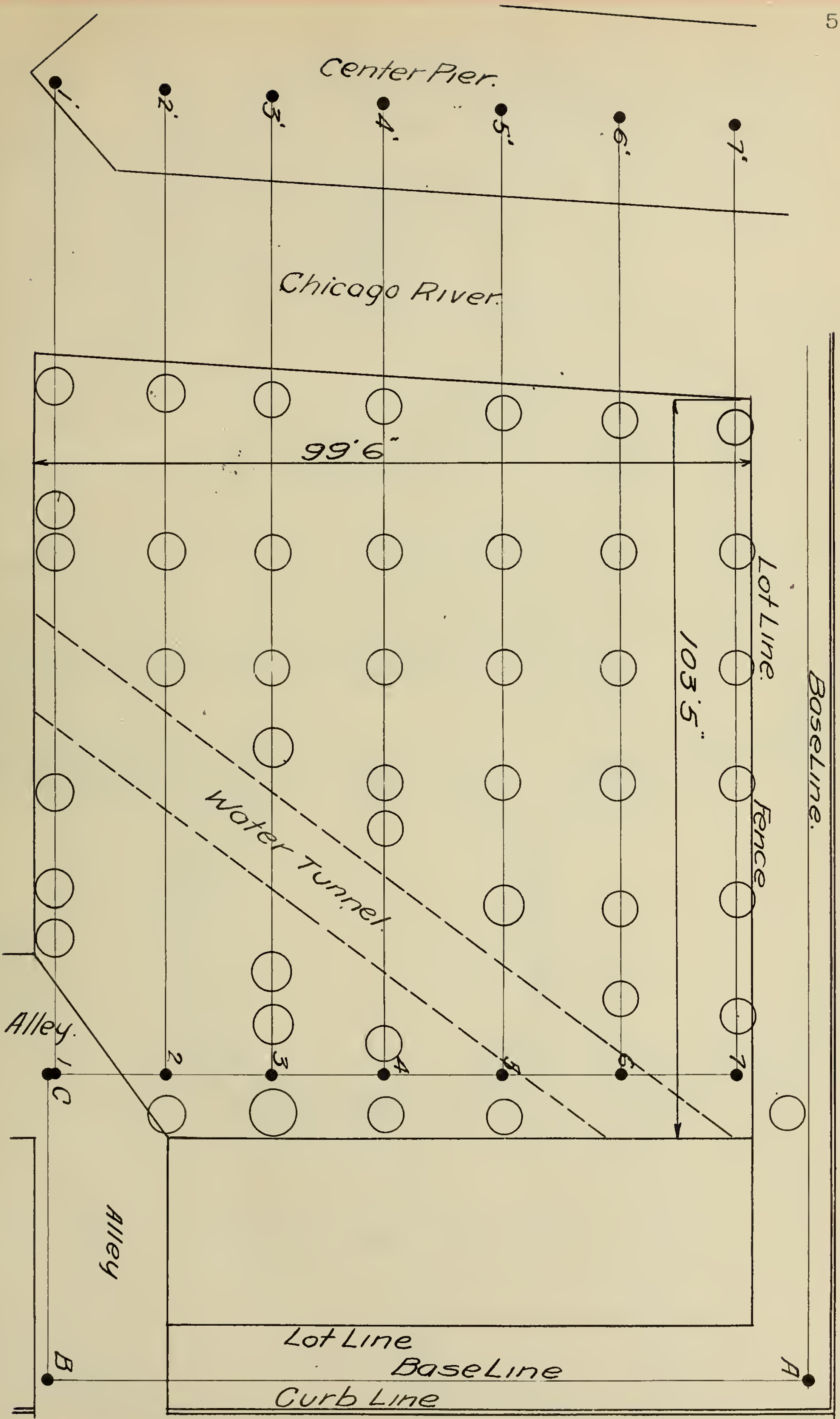

Fig 2.
PLAT OF SITE AND VICINITY.

with two 3" x 3/4" iron rings in a manner shown in Fig. 4,page 6 . The two halves of the ring are placed in position on the inside of the lagging and then fastened together by bolts through the flanges The rings are usually placed about six inches from the top and bottom ends of the lagging respectively.

To sink the caisson a hole is excavated by means of pick and spade,and the material thus loosened is hauled to the top in buckets. This hole is lined with wooden staves put in in uniform lengths as the excavation progresses,and these staves in turn are braced on the inside by iron rings or hoops,also inserted as the work progresses. When the excavation is entirely completed the interior of the caisson is filled with concrete,the lagging and rings being removed as the filling progresses.

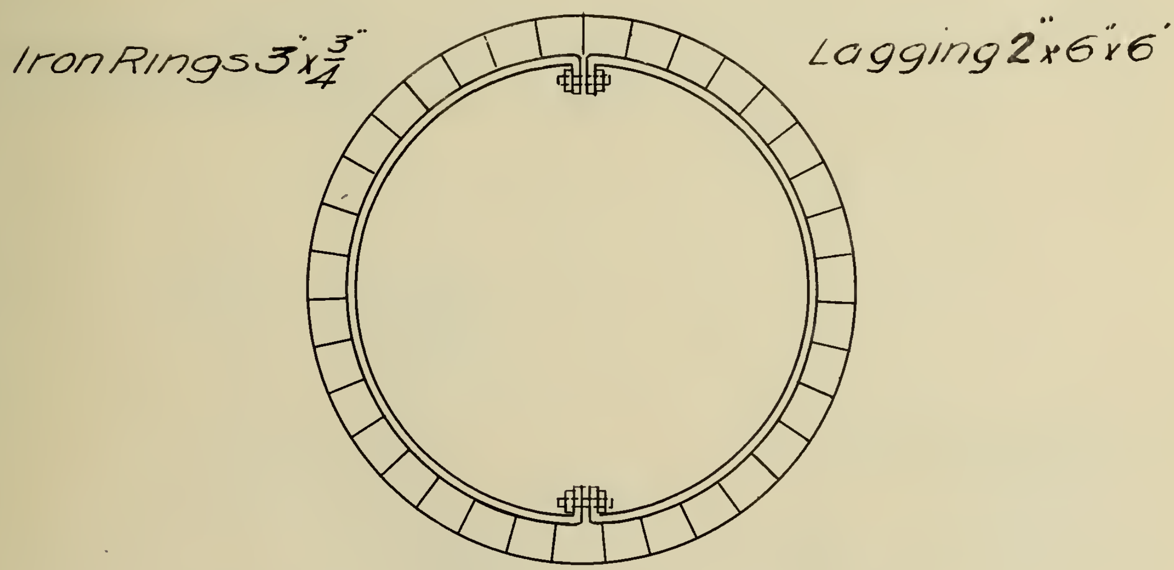

Fig 4.
LAGGING AND RINGS.

In the Grower Building the dimensions and form of the caissons varied according to the conditions met with. Most of the caissons along the lines of the adjoining lots were of the same diameter from top to bottom, and went to bed rock; while the remainder were belled out and went only to hard-pan. The dotted lines around the caissons Fig.1 page 3, represent the outer extremities of the bell. Fig.5 page 7, shows the form of bell employed. The belling out began at the top of the strata of hard-pan on which the caisson was to rest. A condition imposed upon the contractor was as follows; "There shall be at least 7 ft. of hard-pan under the caisson when the excavation is completed. In case this requirement can not be satisfied, the excavation shall be continued until bed rock is reached." Owing to this requirement it was necessary to make borings in each caisson as soon as hard-pan was reached; and several of the caissons that were designed to go only to hard-pan went finally to bed rock.

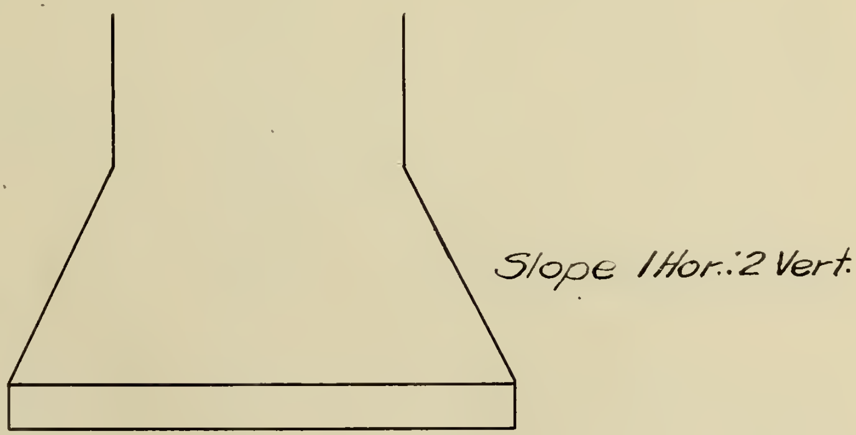

Fig.5

FORM OF BELL EMPLOYED.

In all there were forty-three caissons each being designated by a number, see Fig. 1,page 3. It will be noticed that the numbers in Fig. 1 run higher than forty-three,which was due to the fact that the form of some of the caissons was changed before being sunk,and the latter form was given a new number to prevent confusion.

EXCAVATION IN THE CAISSON.

After the engineer had fixed the center of the caisson the work of sinking progressed as follows: A square hole whose side was about two feet larger than the diameter of the caisson, was excavated to a depth of six feet. A ring was then placed upon the bottom of the pit,and three or four staves were set upon end against the outside of the ring,and clay was dumped between the undisturbed earth and the lagging to hold it in place;and then more staves were added until the circle was complete. Care was taken to set the staves to a true circle and to the proper center. The clay on the outside and the ring on the inside held the lagging very nearly in the form of a vertical cylinder. After the circle was completed the upper ring was put in place and held there by a few nails driven below it into the lagging,and then the clay was filled in between the lagging and the side of the hole.

Next the excavation was continued until another length of lagging could be inserted. The second and subsequent lengths of lagging were kept to proper line and curve by forcing clay behind them. In this way the excavation and caisson building is continued until hard-pan or bed rock is reached.

The spade and the fork were usually the tools employed by the digger to loosen and to handle the material. However, when

working in hard-pan a pick,known as a grub,and a crow-bar became his principal assets. The excavation was carried on continuously, day and night,the only stop occurringwhen the lagging was being set.

For each caisson there was a crew of four men:- one digder,two windlass men,and one helper. The digger attended to all digging,trimming,etc.,and helped to set the lagging. The windlass men hauled the material to the top;and the helper wheeled it to the wagons. While four men could take care of an ordinary caisson, it was often economical to put on an extra windlass man. One lagger was employed to look after the lagging and rings for each shift, when the excavation was straight work.

Fig.6 shows the method of supporting the windlass used in hoisting the clay out of the caissons.

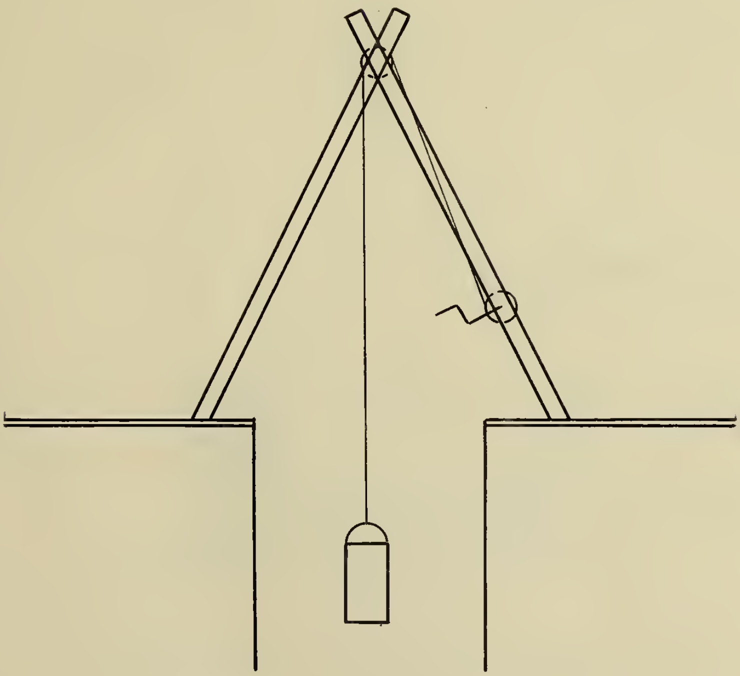

Fig. 6
WINDLASS OVER CAISSON.

The preceding discussion is probably sufficient for all the caissons except those near the river, or those near the water tunnel. In these the difficulties encountered warrant a special description.

RIVER CAISSONS.

The caissons along the river, Nos. 7,8,9,10,11,12 and 13, Fig.1 page 3, were difficult to sink for two reasons, namely: 1, it was difficult to keep out the water; and 2, the soil contained rubbish of all character. These difficulties could have been overcome most economically and efficiently by constructing a water-tight dam along the water front of the site; but the contractor saw fit to rely upon some poorly driven sheeting already in place to keep out the water.

Caisson No. 7 is situated at one corner of the site next to the river, as shown in Fig.6 page10. The old sheeting was found to be insufficient to keep out the water, and hence it was decided

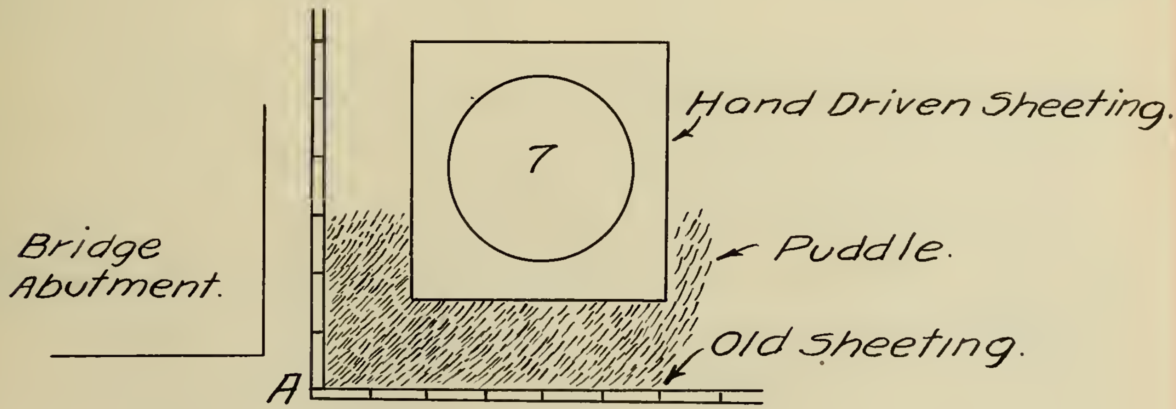

Fig. 7.
LOCATION OF CAISSON NO.7.

to drive by hand six-inch matched sheeting in 10 foot lengths,

about 18 inches inside of the old sheeting, and to puddle between the two. This would keep out the water only temporarily, as the current striking at A, Fig. 7, page10, would seep through the leaky sheeting and soon wash the puddle away. Three rows of hand-driven sheeting were put in before digging could be carried on continuously. When the excavation had reached a depth of 30 ft. and was progressing satisfactorily, an accident interruptedthe work. A boat struck the sheeting at A, knocking the caisson off its center and causing a leak, and rendered all of the work done in sinking practically useless.

A pile-driver was next brought into service. Several pieces of sheeting were driven along the north line at A, and the old puddle was removed; and a new one consisting of clay intermixed with manure was put in, which stopped the leak. The water was then pumped out, and the excavation resumed. Each section of lagging set before the accident had to be realigned, the lowest section being centered first and the successive sections above placed in line with it.

Caisson No. 8, Fig. 1, page 3, was also sunk with considerable difficulty. Inside of the old sheeting three rows of hand-driven sheeting were driven. Next puddle was filled in between the lagging and the sheeting, and also between the latter and the old sheeting -see Fig. 8, page12. The work of excavation in this caisson was carried on intermittently, because of the fact that the puddle walls had frequently to be renewed. However, no other difficulties were encountered.

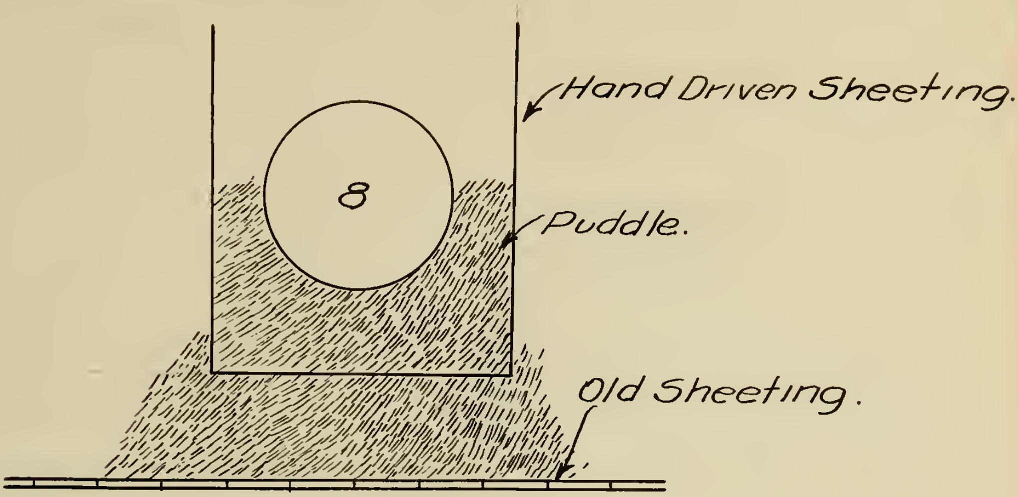

Fig 8

LOCATION OF CAISSON NO.8.

Caisson No.9 was the next attacked. By this time the contractor was thoroughly convinced that it was very expensive as well as very unsatisfactory to use hand-driven wooden sheeting for the caissons along the river front. Accordingly he decided to experiment with power-driven steel sheeting. Fig. 9,page12 , shows the type of steel sheeting used,and the position in which it was driven. The sheeting was made up of 12-inch I beams and 12-inch channels,20 ft. long. The channels were bolted together with the legs facing each other,enough space being left between the legs to admit the web of the I beams. To turn corners the flange of one I beam was riveted to the web of another. After the sheeting was driven the space between the channels was filled with puddle. Small portions being put in at a time and then rammed home with a long rod. Puddle was also added on either side of the steel sheet-

ing. Apparently the problem of keeping out the water had been solved,and the excavation was commenced. However at a depth of about 15 ft. it was found that the steel sheeting intersected the plane of the caisson. One piece had struck an old foundation pile and was deflected out of line. Obviously,it was useless to continue excavation. The steel sheeting was then pulled;and it was at this point that the contractor decided to have the river front dredged out and a substantial dam constructed,see Fig. 10,page14. The dam was composed of Wakefield sheeting 30 ft. long.

In this type of sheeting three plamks are bolted together the flat faces being placed against each other,the middle plank being placed so as to form a grove on one side and a tongue on the other. This dam was very effective in keeping out the water. Caissons Nos. 9,10,11 and 12. were then sunk with no further difficulty.

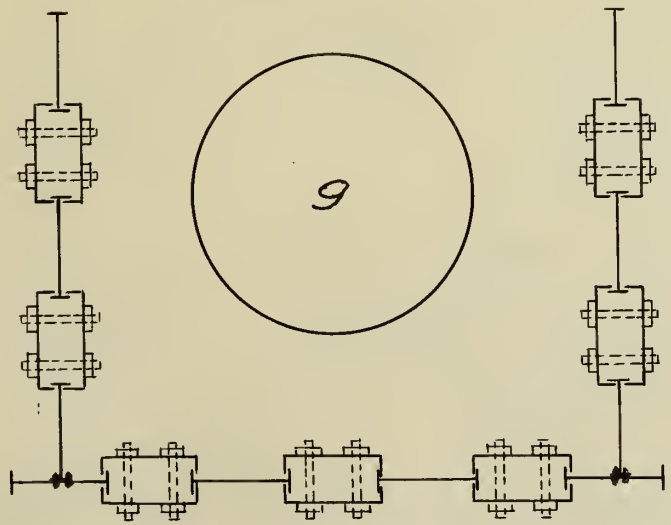

Fig. 9.

STEEL SHEETING AROUND CAISSON NO. 9.

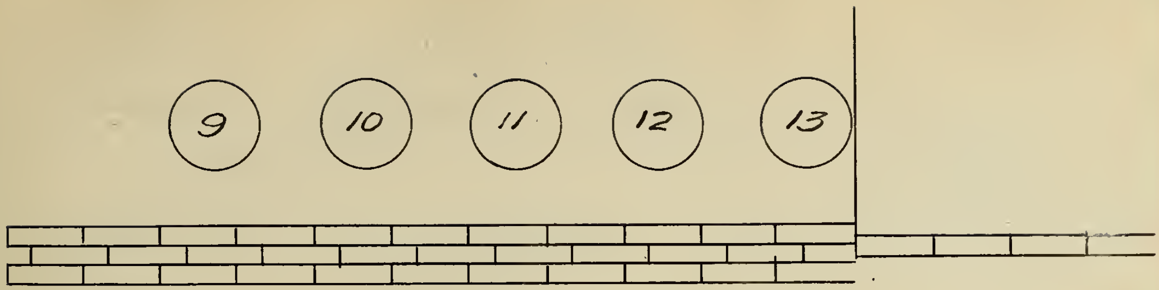

Fig. 10

SHOWING DAM AROUND CAISSONS NO. 9-10-11,12,13.

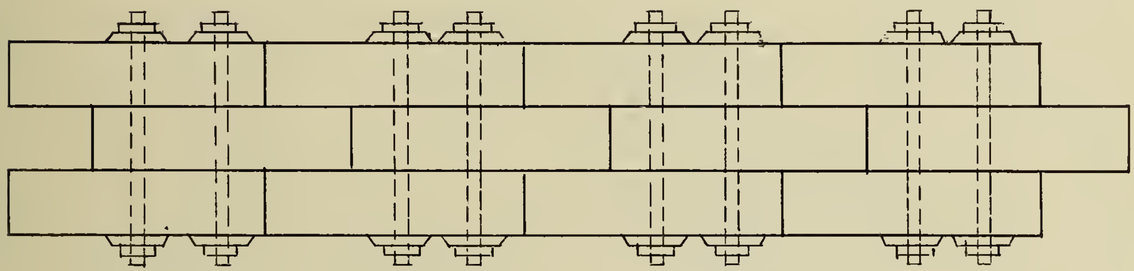

Fig. 11.

DETAILS OF SHEETING.

Caisson No. 13. At A, Fig. 10, page 14, at the south-west corner of the site, was the remains of an old shipping platform, and about 5 ft. from the building was a line of single leaky sheeting; and hence the space between the building and the sheeting was filled with water. It was impossible for the pile-driver to drive a return line of sheeting at A at right angles to the dam; and therefore the space between the sheeting and the wall was completely filled with puddle for a length of 15 ft. No. 13 the last of the river caissons, was then sunk without difficulty.

TUNNEL CAISSONS.

Caissons 1,44,40,35,31,15,16,30,34 and 22 can properly be grouped under the head of tunnel caissons. In the original specifications the contractor was given the choice of two methods in sinking these caissons,namely; 1, the use of air pressure; or 2, the use of inter-locking steel sheet-piling. The fact that the location of the tunnel was known only approximately was sufficient reason for not even attempting to use steel sheet-piling,and so the first of the caissons was sunk under air pressure.

Caisson No. 22, see Fig. 1,page 3,was the first tunnel caisson sunk. The excavation was carried on in the usual manner to a depth of about 45 ft. At this point work had to be stopped because of the inrush of a large volume of water that filled the caisson to a depth of 20 ft. Pumps were then brought into service, and the water was pumped out. An air lock (see Fig. 12,page16) was now lowered into the caisson,set in place,and connected with a compressor. A pressure of 20 lbs. per square inch was required to keep out the water,and as soon as this pressure was attained digging was commenced.

The material excavated in the caisson was hauled to the top through the locks by means of two seperate windlasses placed at the surface. The process was as follows: The bucket was filled with "excavation" at the bottom of the caisson,and then elevated to the inside of the lock (see Fig. 12,page16)by means of a wire cable which passed through the air lock and then through a small aperture in the top of the lock. The air was prevented from escaping through this hole by means of a tightly packed stuffing box through which the hoisting cable passed. When the bucket had been

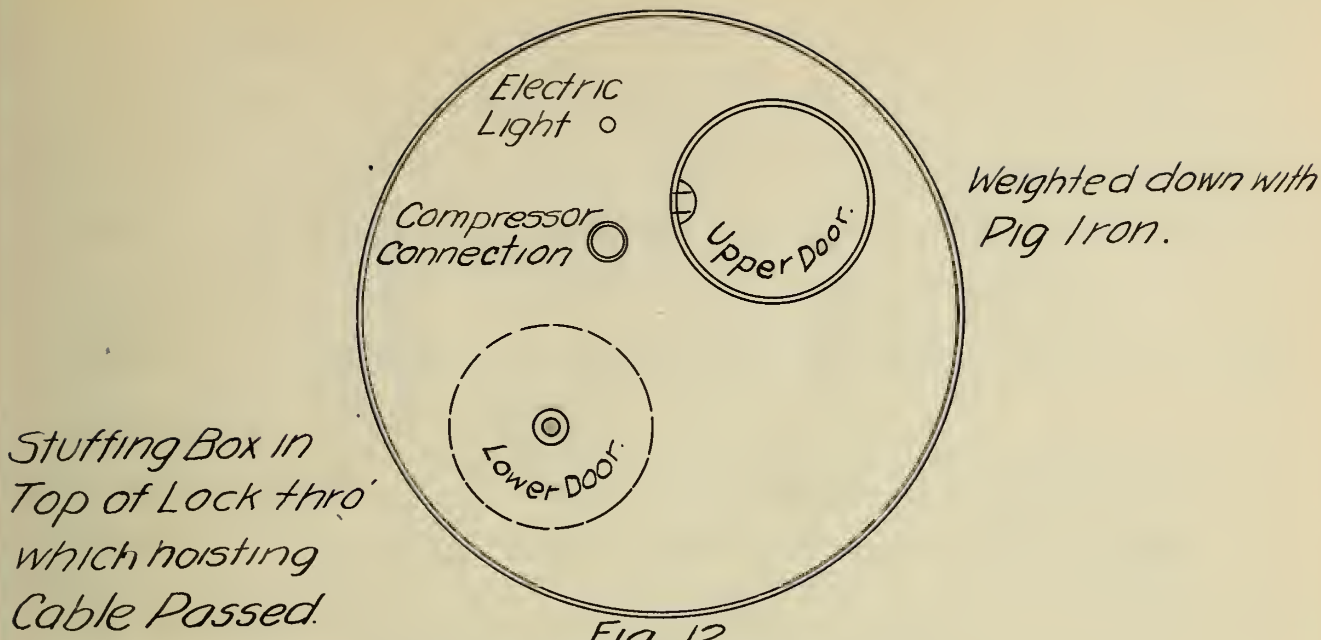

Fig. 12
ELEVATION OF LOCK.

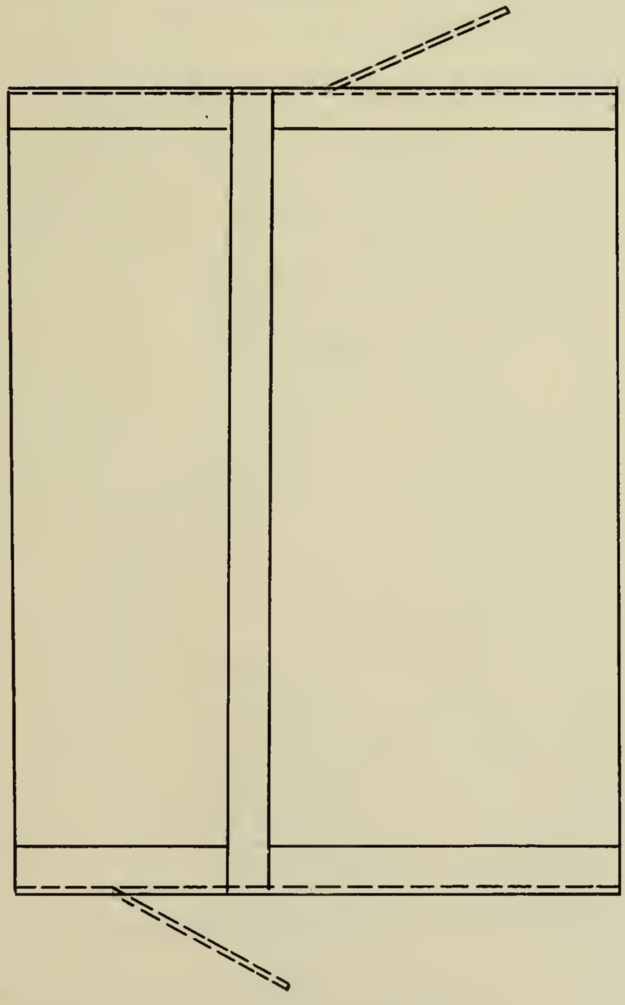

Fig. 12A.
PLAN OF LOCK.

raised through the bottom door into the lock,this door was promptly closed and the upper one opened. The bucket was now hauled to the surface by means of the usual rope hoist. It was impossible to carry on the digging continuously on account of the continual presence of water in the caisson. At least twenty five percent of the digger's time was spent in bailing water. However,the caisson was sunk finally to bed rock.

Caisson No. 15 also was attacked by the pneumatic process. As in No. 22 the sinking was carried on in the manner usual for foundation caissons until a depth of about 40 ft. was reached, when the air lock was inserted and digging commenced under pressure. The excavation progressed satisfactorily to 50 ft.,at which point the diggers were impeded by the continual seeping in of the water. However,the excavation was continued to nearly 60 ft. when it was deemed inadvisable to dig deeper on account of the large amount of water present. Pending an investigation all work on this and other tunnel caissons was suspended.

After a careful study of the facts and conditions in sinking caisson No. 22,and 15, the engineer and contractor came to the conclusion that it was impracticable to sink the caissons along the tunnel by the use of compressed air. Air pressure was successful as long as the material met with was uniform and compact; but the streak of sand running through the soil made the use of the air process impracticable as the air would seep out through the sand so rapidly that it was impossible to maintain any-where near the required pressure. The two alternate plans originally outlined in the specifications for sinking the tunnel caissons had thus proved to be inadequate. Accordingly an investigating

committee was organized to devise a new method of attack for the tunnel caissons. This committee was composed of the city engineer, the architect, two consulting engineers, and a man of practical experience. The plan recomended by them was as follows:- First, increase the number of diggers from one to two, and the number of windlass men from two to three. Second, insert at a depth of ten feet above the tunnel a metallic cylindrical shield having a sharp cutting edge at one end and a flat bearing ring at the other. The shield was to be jacked against the lagging above and into the soil below to a depth of six inches, and the six inches then excavated. This process to be carried on continuously until the excavation was safely ten feet past the tunnel. Third, use only 2 1/2 foot sections of lagging braced with two rings to each section. The committee recomended furthermore that additional borings be made to determine more accurately the location of the tunnel.

The plans and recommendations of the investigators were adopted. As a result of the borings made the proposed location of several of the caissons adjacent to the tunnel was changed. Caissons 27,31,35,40,44,1,34 and 30 were sunk successfully by the plan outlined above. The success of this method can in a great measure be attributed to the speed with which it was carried out. The two diggers were able to carry on excavation almost twice as fast as one would have done. The three windlass men hauled up the material excavated without holding back the diggers. But to the lagger belongs most of the credit for the success of the plan. Setting the lagging was usually a very slow operation; but the lagging for the tunnel caissons was set in half the usual time. The lagger always had the required number of pieces of lagging sawed to the proper

length ready for insertion,and the rings picket out; and thus as soon as the diggers had excavated one length of lagging no time was lost in putting it into place.

Fig.14, page 20,ahows the type of shield used. It was made in three sections,as shown in Fig.. The construction of the shield was open to criticism since rivets were not counter-sunk on the outside,thereby making it very difficult to jack the shield in place.

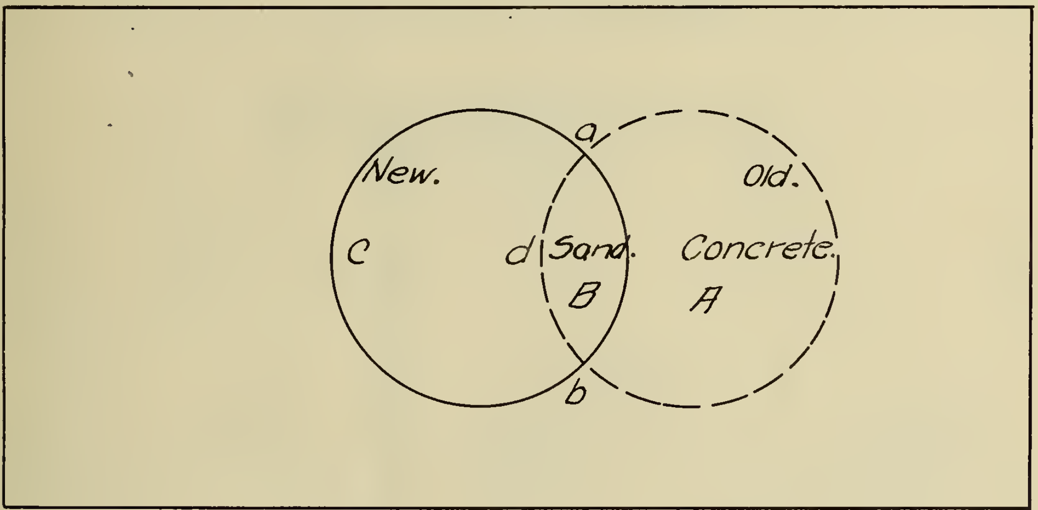

Fig. 12.

CAISSON NO44. SHOWING INTERSECTION OF OLD AND NEW CAISSON.

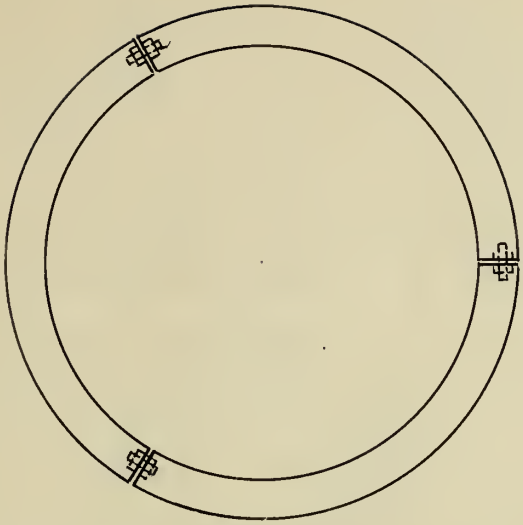

Fig. 13
PLAN OF SHIELD.

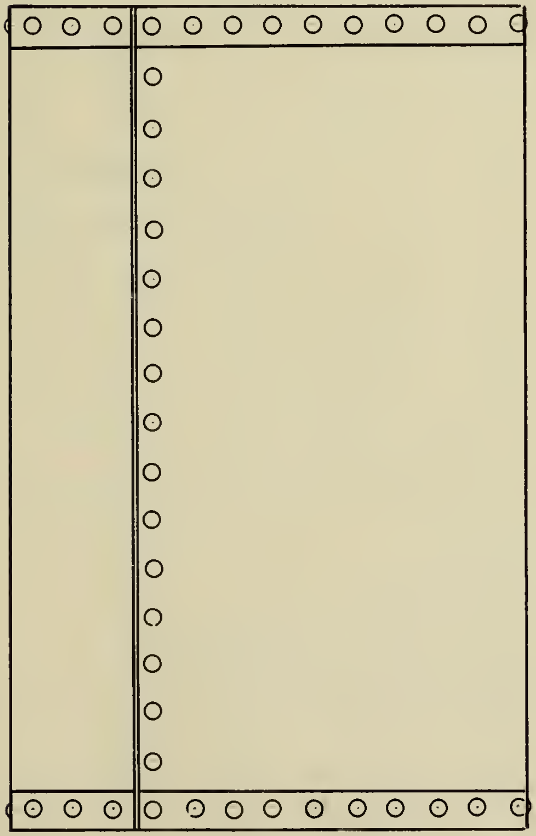

Fig. 14.
ELEVATION OF SHIELD.

Caisson No. 44 deserves special treatment on account of the peculiar conditions encountered. Origionally this caisson was designed to be a pneumatic one; but the excavation for it had been carried on to a depth of about 40 ft. when work was suspended by the engineer on account of the investigation ordered as to the best method to be pursued in sinking the caissons near the tunnel. As a result of this investigation the location of this caisson was moved a slight distance away from the tunnel. The plane of the new caisson intersected that of the old caisson as shown in Fig. 12page 19.When the location of tho caisson was changed,it was intended to excavate a rectangular shaft inclosing both the old and the new locations; but at a depth of about 25 ft. the timbering grew to such large proportions that another expedient was resorted to. The part a-b of the lagging for the new location was inserted in the old caisson at the bottom for a 5-foot length of lagging,and part A was filled with concrete balanced by sand filling in part B. This process was continued upward to the surface of the ground. When the concrete had set the lagging a,d,b was removed and a,c,b was joined to a,b thus completing the circle. The excavation for the newly located caisson was then carried down in the usual manner.

CONCRETE.

The concrete used in filling the caissons was composed of one part of cement,three parts of sand,and four parts of stone. It was mixed by hand in batches of 1 1/8 yards on platforms. The sand and cement were throughly mixed dry;and then the stone and water was added,and the whole mass turned over three times. Next it was deposited in the caisson,one set of lagging having been

removed. When it is remembered that the concrete had to be lowered in some cases to a depth of over 100 ft.,it is apparent that some good method must be employed to put it into place. The usual method in foundations of this kind in Chicago has been to provide a chute through which the concrete is thrown there being two men in the caisson to distribute and tamp it as it comes out of the chute. For this building the architect devised a much simpler method. In mixing the concrete it was shovelled to the brink of the caisson, where two men dropped it a shovel full at a time into the caisson. By a peculiar jerk the concrete was made to leave the shovel in a compact mass and remain in that form till it struck the bottom. The long drop tamped the concrete sufficiently,and the only labor required of the men when they went down in the hole to remove the lagging and rings was to level off the concrete slightly. This method was open to criticism in that the concrete that had taken an initial set was subjected to the repeated blows of the masses of falling concrete. For ordinary caissons only one mixing platform was used;but for the caissons along the tunnel two platforms were provided and seperate gangs worked on each. The two gangs were able to expedite the putting of the concrete in place,thereby reducing the chance of the tunnel's bursting.

HANDLING OF MATERIALS.

The problem of handling materials of construction was difficult since the site covered a very small area,and a large supply of materials had to be kept on hand continually. This made it necessary for the contractor to plan in advance for handling the materials at certain times. At the start a desirable location for the boiler,compressor,and work bench was picked out,and the

caissons in that immediate vicinity were sunk first.

To facilitate the handling of incoming and outgoing material, a board driveway was built from the alley leading to about the center of the site. This driveway was wide enough to accomodate two wagons side by side. One side of it was used as a temporary storeway for the dirt wagons. The material excavated in the various caissons was wheeled in barrows to the driveway and loaded into wagons. Sometimes the wagons were hauled away as soon as they were filled, but more often they were moved by hand into the alley where they remained until evening. This was done to accommodate the cartage contractor because his teams could make many more trips at night than they could in the day time.

Comparatively a small amount of the materials used were hauled to the site in wagons. Practically all of the stone used in the concrete was delivered on scows in boxes of 2 yards each. These boxes were taken off the scow by a derrick and dumped into the stone bin at the south-west corner of the site. The derrick was a floating one owned by the stone company.

The problem of a cement and sand shed was solved in a very simple manner. Owing to the grade to the Madison Street bridge the street is about 15 ft. above the ground level. By clearing out the space underneath the side walk, and boarding up one side, an excellent place to keep the cement and sand was obtained. Furthermore, by cutting a couple of holes in the sidewalk, it became possible to have the sand and cement delivered on Madison Street and thrown through the holes into the improvished sheds.

The lagging was usually hauled in on wagons. However, for a short time during the teamsters strike the lagging was delivered

on scows. The lagging was piled neatly as it was delivered. The rings used to brace the lagging were also carted to the site in wagons. They were sorted and made into seperate piles depending upon their size.

COST.

The data on cost were secured by the writer while in the employment of the contractor. A continuous log book was kept (by the writer for one of the three shifts) showing the daily progress of the work on each caisson,and the number of men employed. The writer had access to the books of the contractor and the prices quoted for materials and labor are the ones actually paid.

The writer will now take up several typical caissons and discuss their cost from beginning to end,under the heads;cost of excavation,cost of concrete,and cost of lagging and rings.

COST OF EXCAVATION.

Since the process of excavation for a caisson is necessarily accompanied by the setting of lagging,and furthermore since the lagging is set practically by the same men that carry on the excavation,any discussion of the cost of excavation must necessarily include the cost of setting the lagging.

The cost of sinking the caissons varied somewhat with their depth and position and will be concidered under the following heads :- 1. Ordinary Caissons to hard-pan; 2. Ordinary Caissons to bad rock; 3. Tunnel Caissons with short lagging; 4. Tunnel Caissons by pneumatic process; 5. River Caissons.

1. Ordinary Caissons to Hard-Pan. Caisson No. 32, was 4 ft. 6 inches in diameter and was sunk to hard-pan at a depth of 78.9. The details of the cost are given in Table 1,page25. The

number of cubic yards excavated was 47.0 ; and consequently the cost per cubic yard in place was \$253.80 ÷ 47.0 =\$5.38.

TABLE I

COST OF EXCAVATING CAISSON NO.32

Kind of Labor	Hours Each Day							Total Hours.	Price Per Hour	Total Amount.
	1	2	3	4	5	6	7			
Diggers.	24	24	24	12	24	24	16	148	.50	\$74.00
Windlass Men	48	48	48	24	48	48	32	296	.40	\$118.40
Helpers	24	24	24	12	24	24	16	148	.30	\$44.40
Laggers	3	3	5	4	5	8	6	34	.50	\$17.00
Total								626		\$253.80
Daily Prog.	10	14.8	19.5	8.5	10.3	11.2	3.8			
Succ. Depths	10	24.8	44.3	52.8	63.1	74.3	78.9			
Diameter of Caisson 4' 6"								Contents 47 Cu.Yds.		Cost \$5.38 Per Cu.Yd.

The cost of hauling the material away from the site was .60 cents per cubic yard, measured in the wagon box: but no data are known giving the relation between measurement in place and in the wagon box.

Caissons No. 29 and 40 were of the ordinary type, and the details of the cost of sinking are given in Tables 2 and 3 page 26.

2. Ordinary Caissons to Bed Rock. Three caissons, Nos. 19, 16, and 20, were sunk to bed rock by the usual method.

Caisson No. 19 was 5 ft. 4 inches in diameter and was sunk to a depth of 99 ft. 8 inches. Up to the time of sinking this

TABLE 2.

COST OF EXCAVATING CAISSON NO 29.

Kind of Labor	Hours Each Day 1	2	3	4	5	6	7	Total Hours	Price Per Hour	Total Amount.
Diggers	12	24	40	40	40	12	–	168	·50	$84.00
Windlass Men	24	48	48	48	72	24	–	264	·40	$105.60
Helpers	12	24	24	24	24	12	–	120	·30	$36.00
Laggers	4	5	8	5	5	3	–	30	·50	$15.00
Total								582		$240.60
Daily Prog.	6	15.3	23.7	15.5	10.5	4.0	–			
Succ. Depths	6	21.3	45.0	61.5	72.1	76.1	–			

Diameter of Caisson 5'0" Contents 56 Cu. Yds. Cost $4.30 Per Cu. Yd.

TABLE 3.

COST OF EXCAVATING CAISSON NO 40

Kind of Labor	Hours Each Day 1	2	3	4	5	6	7	Total Hours	Price Per Hour	Total Amount.
Diggers.	8	8	24	48	48	48	48	280	·50	$140.00
Windlass Men.	16	16	48	48	72	72	72	344	·40	$137.60
Helpers	8	8	24	24	24	24	24	136	·30	$40.80
Laggers.	3	2	6	8	8	10	8	45	50	$22.50
Total								905		$330.90
Daily Prog.	5	5	10	27.8	14.1	10.0	5.7			
Succ. Depths	5	10	20	47.8	61.9	71.9	77.6			

Diameter of Caisson 5'9" Contents 72 Cu. Yds. Cost $4.34 Per Cu. Yd.

caisson the men had worked in three eight-hour shifts. However the plan of having only two shifts of twelve hours each was tried in sinking No. 19. Boulders were encountered in sinking this caisson, which increases the cost somewhat; but this phase will be concidered latter. The cost of sinking 19 is given in Table 4 below.

The cost of sinking Nos.16 and 20, are given in Tables 5 and 6, page 28.

3. Tunnel Caissons with Short Lagging. Caisson No.35 was sunk by the shield and short-lagging process; and the cost is shown in Table 7, page 29.

TABLE 4.

COST OF EXCAVATING CAISSON NO 19.

Kind of Labor	Hours Each Day										Total Hours.	Price Per Hour	Total Amount.
	1	2	3	4	5	6	7	8	9	10			
Diggers.	40	28	37^2	20^2	4	33^2	25	25	25	50	298^2	.50	$149.00
Windlass Men	40	57	50	49^2	8	49	50	75	50	50	478^2	.40	$191.40
Helpers	24	28	24	28^2	4	33^2	25	24	24	24	231	.30	$6930
Laggers.	6	6	8	6	3	6	8	8	6	6	63	.50	$31.50
Total.											1070		$441.20
Daily Prog.	15	68	17.2	17.	4.0	8.6	10.6	3.0	6.6	11.0			
Succ. Depth	15	21.8	39.0	56	60	68.6	79.2	87.2	88.8	99.8			
Diameter of Caisson 5' 4" Contents 83 Cu. Yds. Cost Per Cu. Yd. $535													

Caisson No. 31 was sunk by the ordinary process until the bottom of the caisson was about 10 ft. above the top of the tunnel, when the short-lagging process without the shield was in-

TABLE 5

COST OF EXCAVATING CAISSON NO 16

Kind of Labor	Hours Each Day 1	2	3	4	5	6	7	8	9	Total Hours.	Price Per Hour.	Total Amount.
Diggers	48	36	48	24	24	48	48	48	10	334	.50	$167.00
Windlass Men	44	72	48	48	48	72	72	72	30	506	.40	$202.40
Helpers.	40	24	24	24	24	24	24	24	10	218	.30	$65.40
Laggers	8	8	12	12	12	12	8	8	10	90	50	$45.00
Total										1148		$479.80
Daily Prog.	15	24	16.8	7.9	8.5	7.8	6.6	11.2	2.1			
Succ. Depths	15	39	55.8	63.7	72.2	80.0	86.6	97.8	99.9			

Diameter of Caisson 6'2" Contents 111 Cu. Yds. Cost $4.42 Per Cu. Yd.

TABLE 6

COST OF EXCAVATING CAISSON 20

Kind of Labor	Hours Each Day 1	2	3	4	5	6	7	8	9	10	Total Hours.	Price Per Hour	Total Amount.
Diggers	48	48	48	48	24	24	48	48	48	48	432	.50	$216.00
Windlass Men.	48	72	72	48	48	48	72	72	72	72	624	.40	$256.80
Helpers	24	24	24	24	24	24	24	24	24	24	240	.30	$72.00
Laggers	8	8	12	8	12	12	10	12	12	12	106	.50	53.00
Total											1402		$597.80
Daily Prog.	16	17.7	17.0	13.2	5.0	7.7	4.5	6.5	6.2	5.7			
Succ. Depths.	16	33.7	50.7	63.9	68.9	76.6	81.1	87.6	93.8	99.5			

Diameter of Caisson 6'9" Contents 132 Cu. Yds. Cost $4.52 Per Cu. Yd.

TABLE 7

COST OF EXCAVATING CAISSON NO 35.

Kind of Labor	Hours Each Day 1	2	3	4	5	6	7	8	9	Total Hours	Price Per Hours	Total Amount
Diggers	12	8	4	48	16	48	48	48	16	248	.50	$124.00
Windlass	36	8	4	48	24	72	72	72	24	360	.40	$144.00
Helpers	12	8	4	24	24	36	36	36	12	192	.30	$57.60
Laggers	3	4	2	16	6	8	8	8	8	53	.50	$26.50
Total										853		$352.10
Daily Prog	12	3.8	4.2	21.0	8.0	7.4	10.2	9.6	3.7			
Succ. Depth	12	15.8	20.0	41.0	49	56.4	66.6	76.2	79.9			
Diameter of Caisson 5'0" Contents 58 Cu.Yds. Cost $609 Per Cu.Yd.												

TABLE 8

COST OF EXCAVATING CAISSON NO 31.

	Hours Each Day 1	2	3	4	5	6	7	Total Hours	Price Per Hour	Total Amount
Diggers	16	32	24	48	24	48	48	230	.50	$115.00
Windlass	16	48	48	72	36	72	72	364	.40	$145.60
Helpers	–	24	24	36	18	36	36	174	30	$52.20
Laggers	–	6	12	12	4	12	8	54	50	$27.00
Total								822		$339.80
Daily Prog.	10.0	10.6	17.4	9.3	4.9	14.9	7.9			
Succ. Depths	10.0	20.6	38.0	49.3	54.2	69.3	77.0			
Diameter of Caisson 5'4" Contents 63.6 Cu.Yds. Cost $5.35 Per Cu.Yd.										

troduced; the cost of this caisson is given in Table 8.,page 29.

4. Tunnel Caissons by Pneumatic process. Caisson No. 22 was sunk by the pneumatic process already described. Its cost is shown in Table 9.,page 31.

5. River Caissons. There were seven river caissons; but the cost of only two willbe given here. Caisson No.8 is typical of the river caissons,and its cost is given in Table 10. Caisson No.7 was the most difficult of the river caissons to sink,and the most expensive of any on the job. The data concerning its cost is given in Table 11, page 32.

THE COST OF EXCAVATION.

Reasons for Different Cost. The cost per cubic yard of the ordinary caissons sunk to hard-pan varies concidorably No. 32 being $5.38, No.29 $4.30, and No.40 $4.34, giving an average cost for the three of $4.67 per cubic yard. In this case the average cost really means very little,because the slightest hitch or delay in the excavation caused the cost to rise very rapidly. It was probably due to a series of such little delays that made the cost of excavating caisson No. 32 greater than the others. No. 29 and 40 seem to more fairly represent the cost of an ordinary caisson sunk to hard-pan;and therefore it would be reasonable to assume that the average price per cubic yard would be the mean of the two or $4.32 per cubic yard.

The cost of sinking the ordinary caissons to bed rock does not show quite as large a variance as was shown in the case of those sunk only to hard-pan; for example, No. 19 cost $5.35 per cubic yard, No. 16 $4.42, and No. 20 $4.52. The cost of excavation of No. 19 was increased greatly by the continual presence of large

TABLE 9.

COST OF EXCAVATING PNEUMATIC CAISSON NO 22

Kind of Labor	Hours Each Day																		Total Hours.	Price Per Hour.	Total Amount.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18			
Diggers	24	24	48	16	16	24	16	24	24	24	36	48	24	24	24	24	24	48	444	.50	$220.00
Windlass	48	48	32	32	—	72	48	72	72	72	108	144	72	72	72	72	72	24	1148	.40	$459.20
Helpers	24	24	24	8	-	24	16	24	24	24	36	48	24	24	24	24	24	8	404	.30	$121.20
Locktenders					16	24	16	24	24	24	36	48	24	24	24	24	24	8	324	.50	$162.00
Engineers					16	24	24	24	24	24	36	48	24	24	24	24	24	8	324	.60	$194.40
Laggers	4	4	4	-	8	12	8	8	8	10	15	20	8	8	8	8	8	8	149	.50	$74.50
Total																			2793		$1233.30
Daily Prog.	10	8.2	248	5.3	-	4.5	2.1	32	2.0	4.5	47	47	1.0	3.8	5.0	4.1	7.1	2.2			
Succ. Depth.	10	18.2	24.3	48.5	48.5	53.9	56.0	59.2	61.3	65.8	70.5	75.2	76.2	80.0	85.0	89.1	97	99.9			
Diameter of Caisson 6'2" Contents 111 Cu.Yds. Cost Per Cu.Yd. $11.08																					

Note. On the 11th and 12th days of work the same number of men were employed. However, on account of these days falling on Saturday and Sunday respectively the men were paid time and a half for work on the 11th and double time for the 12th.

TABLE 10
COST OF EXCAVATING RIVER CAISSON NO 8.

Kind of Labor	Hours Each Day 1	2	3	4	5	6	7	8	9	10	11	12	Total Hours	Price Per Hour	Total Amount
Diggers	16	16	16	13	12^2	16	4	33	25	25	25	50	251^2	·50	$125.50
Windlass	16	-	8	13	25	41	8	41	50	50	50	75	381	·40	$15240
Helpers	8	8	8	8	12^2	20^2	4	33	25	25	25	25	202	·30	$60.60
Laggers				6	-	8	8	8	8	8	8	12	66	·50	$3300
Pump Engineer				12	12	12	4						40	60	$2400
Total													940^2		$395.50
Daily Prog.	Sheeting.							6.5	12.3	11.3	8.5	13.3			
Succ Depths							25.	31.5	43.8	54.5	63	76.6			

Diameter of Caisson 4′ 6″ Contents 46 Cu. Yds Cost $8.60 Per Cu. Yd.

TABLE 11
COST OF EXCAVATING RIVER CAISSON NO 7.

Kind of Labor	Hours Each Day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total Hours	Price Per Hour	Total Amount
Diggers	24	24	16	24	-	24	24	12	24	-	-	-	24	24	24	48	16	310	·50	$155.00
Windlass	24	24	16	24	-	24	24	12	24	-	-	-	48	48	48	72	48	436	40	$174.40
Helpers	12	12	8	12	12	12	12	12	12	-	-	-	24	24	24	24	16	216	30	$64.80
Laggers				6	-	8	12	12	12	-	-	-	12	12	12	12	12	110	·50	$55·00
Pump. Engineer					12	12	8	12	12			-	12	-	-	-	-	68	60	$4080
Pile Driver & Crew									10	5	5	-	-	-	-	-	-	20	$5.00	$100.00
Total																		1160		$590.00
Daily Prog.														55	8.9	7.2	3.6			
Succ. Depths				20.3			40.3						52	57.5	61.4	73.6	76.6			

Diameter of Caisson 4′6″ Contents 46 Cu. Yds. Cost $12.82 Per Cu. Yd.

unwieldly boulders encountered between -80 and -90 ft. Since the specifications forbade blasting, the boulders had to be drilled and broken up before they could be elevated to the surface. The windlass men had therefore very little to do while the diggers were breaking the rock; but were kept in constant attendance at the windlass. The natural conclusion is that the deeper the excavation goes, the more costly it becomes. This is not always true, however, as veins and pockets of sand are frequently met in the lower depths, and are excavated so easily that the average cost per cubic yard of excavation for the caisson is thereby greatly diminished.

In the preceding tables the cost of sinking caissons No. 35 and 31 by the short-lagging method is given. As before mentioned, in No. 35 the metallic shield was used, and it was probably due to this fact that the cost of excavation per cubic yard ran considerably higher than that of No. 31. It took a great deal of time to keep the shield jacked ahead of the excavation, and during the process of jacking the windlass men and laborers were necessarily idle. The increased unit cost of excavating by the short-lagging method can be traced to the amount of extra time spent in setting the lagging, and also to the necessary idleness of the men working on top. The two costs quoted, $6.09 per cubic yard with the shield and short-lagging process and $5.35 for the short-lagging process alone, are fairly typical of the respective methods.

The cost of sinking No. 22, the only caisson sunk by the pneumatic process, , is given in Table 9 page 31. As this is the only caisson sunk by this method, it is impossible to make any comparison. It does seem, however, that the cost is slightly excessive. The only way to account for this is by the fact that it

was the pioneer of its kind,at least on this job; and the excavation crew did not get to working as smoothly as they probably have on latter caissons.

The cost of excavating the river caissons,No.8 and No. 7, is given in Tables 10 and 11. As before stated No. 8 was typical, of the river caissons,and No. 7 quite out of the ordinary. While No. 8 was sunk a great deal cheaper than No. 7,its cost and the cost of all the other river caissons,could have been diminished greatly if a little forethought had been given to the matter by the contractor. Driving sheeting by hand proved to be a very expensive operation,and if the contractor had done away with it entirely he would have saved a great deal of time and money. In the opinion of the writer,the river front should have been dredged out and a good water-tight dam built before the river caissons were attacked.

Type of Labor. In the previous dis cussion of cost nothing has been said about the type of men that carry on this work in Chicago. The digging is nearly always done by negroes or Irishmen; and the windlass men are generally of the same type,though occasionally other nationalities are represented. The helpers are of all nationalities,with the negroes,Irishmen,and Italians in the majority.

On most of the caisson foundations constructed in Chicago,the caissons have been of a sufficient size to warrant two men digging in the caisson at the same time; and because of this fact the diggers pair off and always work together. It is very unwise and at the same time nearly impossible to separate a team of diggers. Frequently complete crews work together composed of

two diggers, three windlass men, and a helper. The negroes especially show a tendency to work in this way. It is a difficult matter to decide whether the negro or the Irish digger accomplishes the more work. From the writer's observation and experience it appears that the Irishmen individually excel the negroes; but on the other hand two negro diggers working together will accomplish more than the same number of Irishmen. A complete caisson crew of negroes do better work than any combination that the writer has ever heard of or witnessed.

The men doing this class of work are all members of the "Hod Carriers and Building Laborers Union"; and as a rule are sober and industrious.

COST OF CONCRETE.

Mixing. There is very little range of cost of mixing and depositing concrete in the caissons and hence data for only two caissons will be given. Table 12 page , shows the amount of labor required and the cost per cubic yard for accomplishing the above operations in caissons 10 and 35.

TABLE 12

COST OF MIXING AND DEPOSITING CONCRETE.

Caisson	No. Men	Hours Each	Total Hours	Price Per Hour	Total Amount	Volume Cu. Yds	Price Per Cubic Yard.
No. 10	4	24	96	.30	$28.80	46.0	62.6¢
No 35	9	13	117	.30	$35.10	58.0	60.5.

The sand and cement were throughly mixed dry,and then,the stone and water were added simultaneously,and all were turned two times. The costs given above for mixing and depositing the concrete in the caissons seems rather low. This can be accounted for in part by the fact that very little wheeling of materials had to be done.

Materials. Using the data in Kidder's Pocket-Book for Architects for the ingredients in a cubic yard of concrete,it is estimated that to make one yard of concrete in the proportions of one cement:three sand:four stone: it would take 1.37 bbls. of cement, 0.58 cubic yards of sand, and 0.80 cubic yards of stone. The prices paid for the above materials on this job were; Cement \$1.40 per bbl.;Sand \$1.60 per cubic yard;and Stone \$1.25 per cubic yard. The cost therefore for the materials used in a cubic yard of concrete was \$3.84 as shown in Table 13.

TABLE 13
COST OF MATERIALS FOR ONE CU. YD. OF CONCRETE.

Material.	Quantity.	Price Paid.	Amount.
Cement	1.37 bbls.	\$1.40 Per bbl.	\$1.92
Sand	.58 Cu.Yds.	\$1.60 Per Cu.Yd.	.92
Stone	.80 Cu.Yds.	\$1.25 Per Cu.Yd.	\$1.00
Total			\$3.84

Combining the cost of materials for one cubic yard of concrete,with the average cost of mixing and depositing the same in the caisson we have the complete cost of a cubic yard in place or \$4.45.

COST OF LAGGING AND RINGS.

Lagging was paid for on the basis of \$19.00 per thousand feet B.M. The cost of the lagging for a 4 foot 6 inch caisson sunk to a depth of 76 ft. would therefore be 2.886 x \$19.00 or \$54.53

Rings were paid for at the rate of \$2.45 per 100 lbs. A 4 foot 6 inch ring weighs 110 lbs. Since two rings were used to each 6 foot section of lagging, the cost of rings for a caisson of the above size would be \$35.03 .

The contract price lump sum for this job was \$73000. and in addition to this \$6000. was allowed for extra work.

The writer wishes to express his sincere thanks to Mr J. E. Roemheld of the firm of Roemheld and Gallery for much of the information and data that is herein given.